National Aeronautics and Space Administration

First-Principle Dynamic Electro-Thermal Numerical Model of the Radiation Budget Instrument

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RBI
Radiation Budget Instrument

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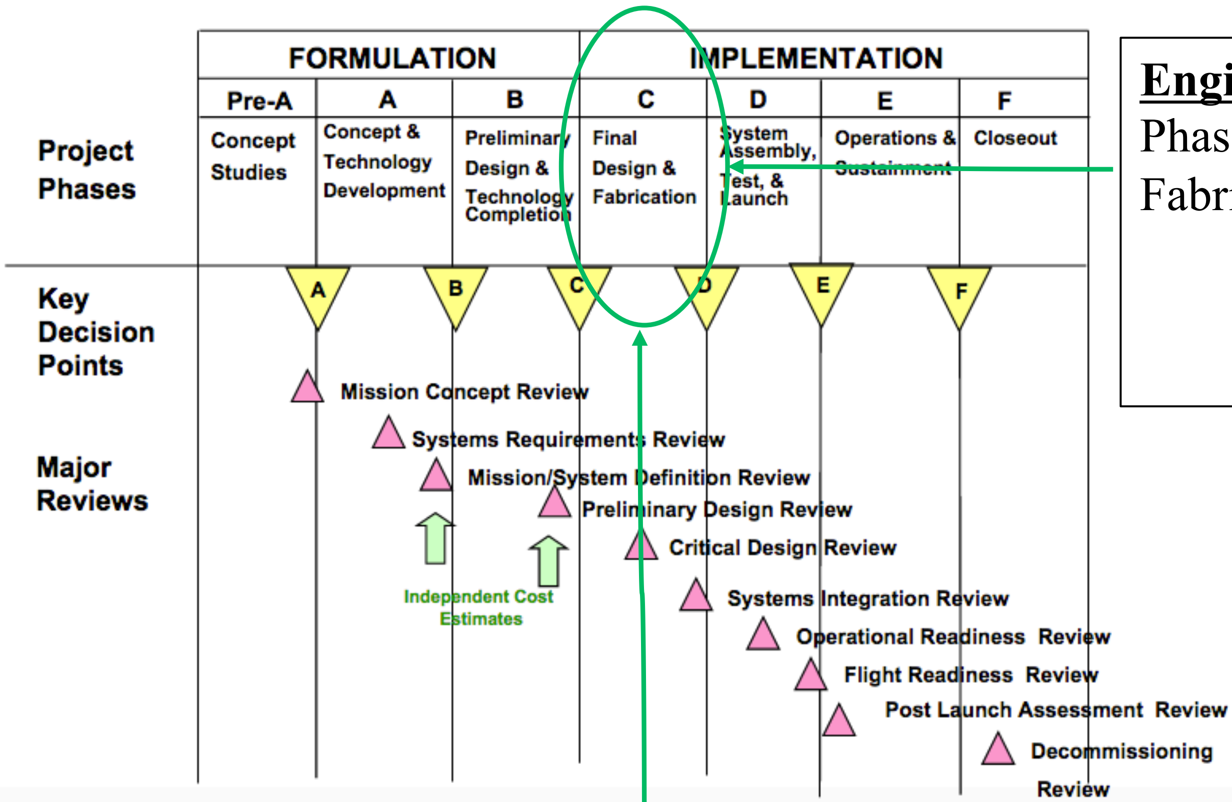
Overview

- Vision Statement
- Current Schedule
- Modeling Team
- Model Components
  - Instrument Model
  - Earth Model
- Correlation with Hardware (EDU/FU)
- Current Status
- Benefits
- Future Resources
- Questions

Vision Statement

- Develop a radiometric system model that consists of:
  - RBI instrument
  - Realistic earth model that is based on real observations from the CERES program.
- Assess the accurate performance of the instrument during its design and build phase and how it impacts the science data products
  - Quantify secondary and tertiary influences in the data products
- Support mission operations and data analysis - Phase E of the RBI program.
- Sustain the RBI long-term mission life by creating a single-platform tool to benefit long term maintenance and cost.

Current RBI Project Phase



<u>Engineering-Led Effort</u>

Phase C: Final Design and Fabrication

- Demonstrate that the detailed system design meets requirements

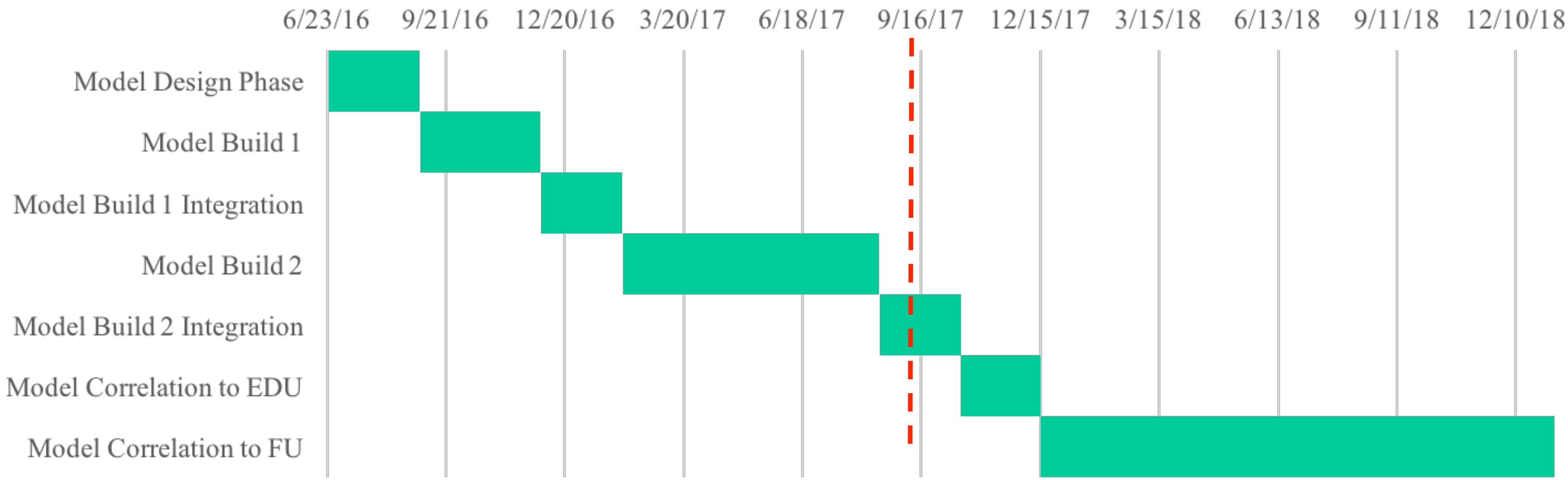
<u>Science-Led Effort</u>

Develop the end-to-end model of the science signal chain: Photons in to bits/counts out.

- To be correlated to the Engineering Development Units at the end of Phase C
- To be correlated to the Flight Unit at the end of Phase D
- Support Mission Operations and Data Analysis in Phase E

Radiometric System Model Development Schedule

Tasks are tied to instrument development and are not independent efforts



Build 1

- Modeling of the individual instrument subcomponents
- Monochromatic sources
- Single telescope (Total)
- Single sided

Integration Phase

- Develop the approach on data transfer between the different subcomponents
- Define interfaces

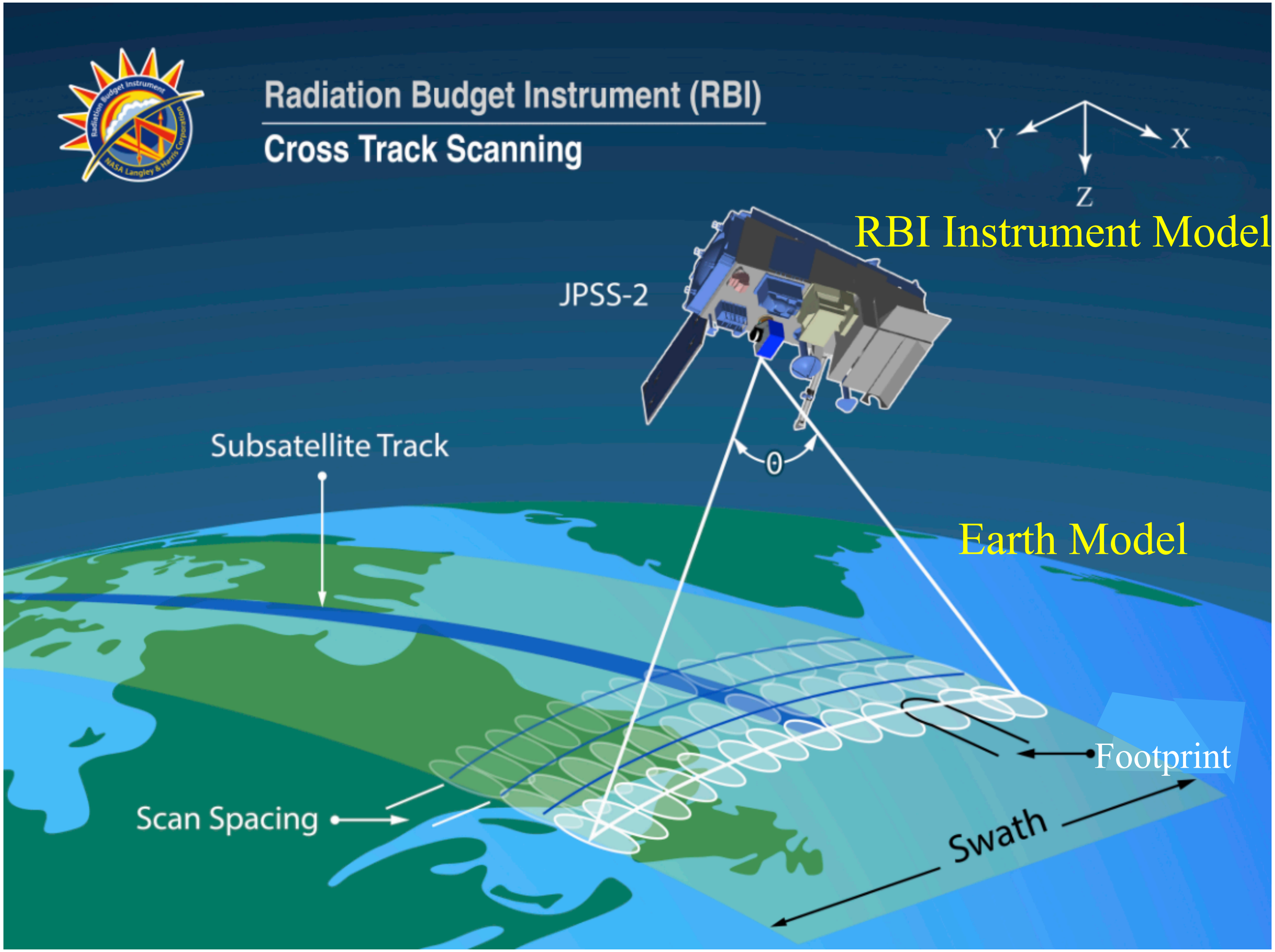
Build 2

- Geo-scenes
- Broadband sources
- All Three telescopes
- Double sided

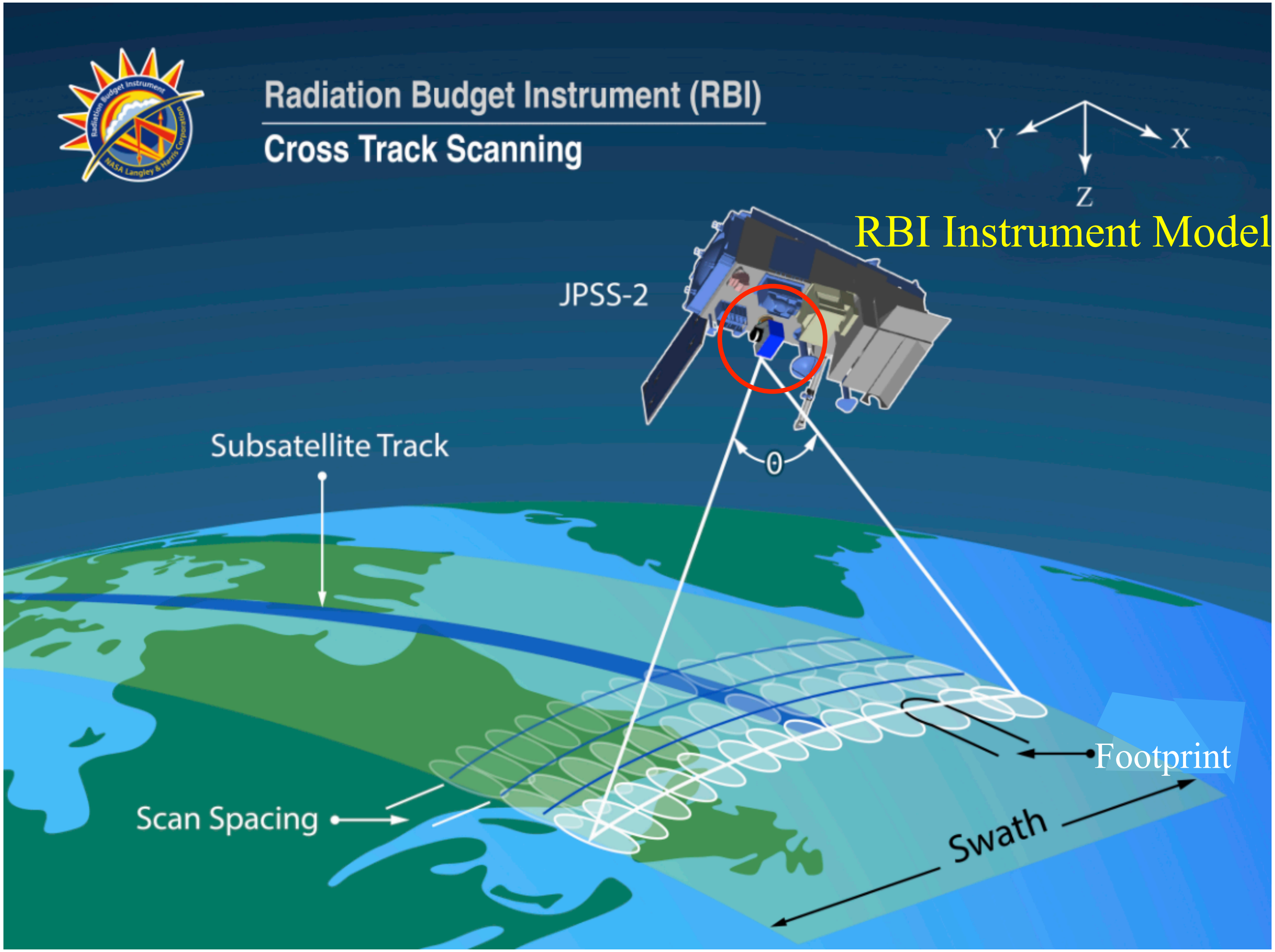
Multi-Disciplinary Team

- **Kory Priestley (NASA LaRC – Science)**
  - Project Scientist – Task Lead
- **Anum Barki (NASA LaRC – Science)**
  - Responsible for leading the design, modeling, and implementation of the End-to-End Radiometric System model of the RBI instrument.
    - Includes modeling of the Earth scenes, interfaces between the sub-components, ICT (Scott Forsythe, Intern)
  - Validate/correlate model with test results of hardware (EDU and FM)
  - Investigate difference in instrument response to on-board and ground calibration sources
- **Bob Mahan and Vinh Nguyen (Virginia Tech)**
  - Responsible for modeling the RBI sensor module (all three channels) using ray-tracing principles
  - Support the Langley calibration team in analyzing the impacts of different design changes (e.g. stray light, dual filters)
- **Brian Vick and Jonathan Pfab (Virginia Tech)**
  - Developing an Electro-Thermal model of the RBI focal plane module
- **Bob Akamine (NASA LaRC – Engineering)**
  - Developing a tool that models the RBI's electronics signal chain.
- **Shawn Mcleod (NASA LaRC – Engineering)**
  - Providing the thermal support, in specific, looking at the thermal design of the RBI telescope.
- **Steven Tobin (NASA LaRC – Engineering)**
  - Providing thermal support, in specific, looking at the ICT and verifying that Harris meets their derived requirements on the ICT.
- **Craig Turczynski and Cindy Young (NASA LaRC – Engineering and Science)**
  - Providing support in modeling the SCT using Zemax (Craig) and Ray-tracing principles (Cindy).

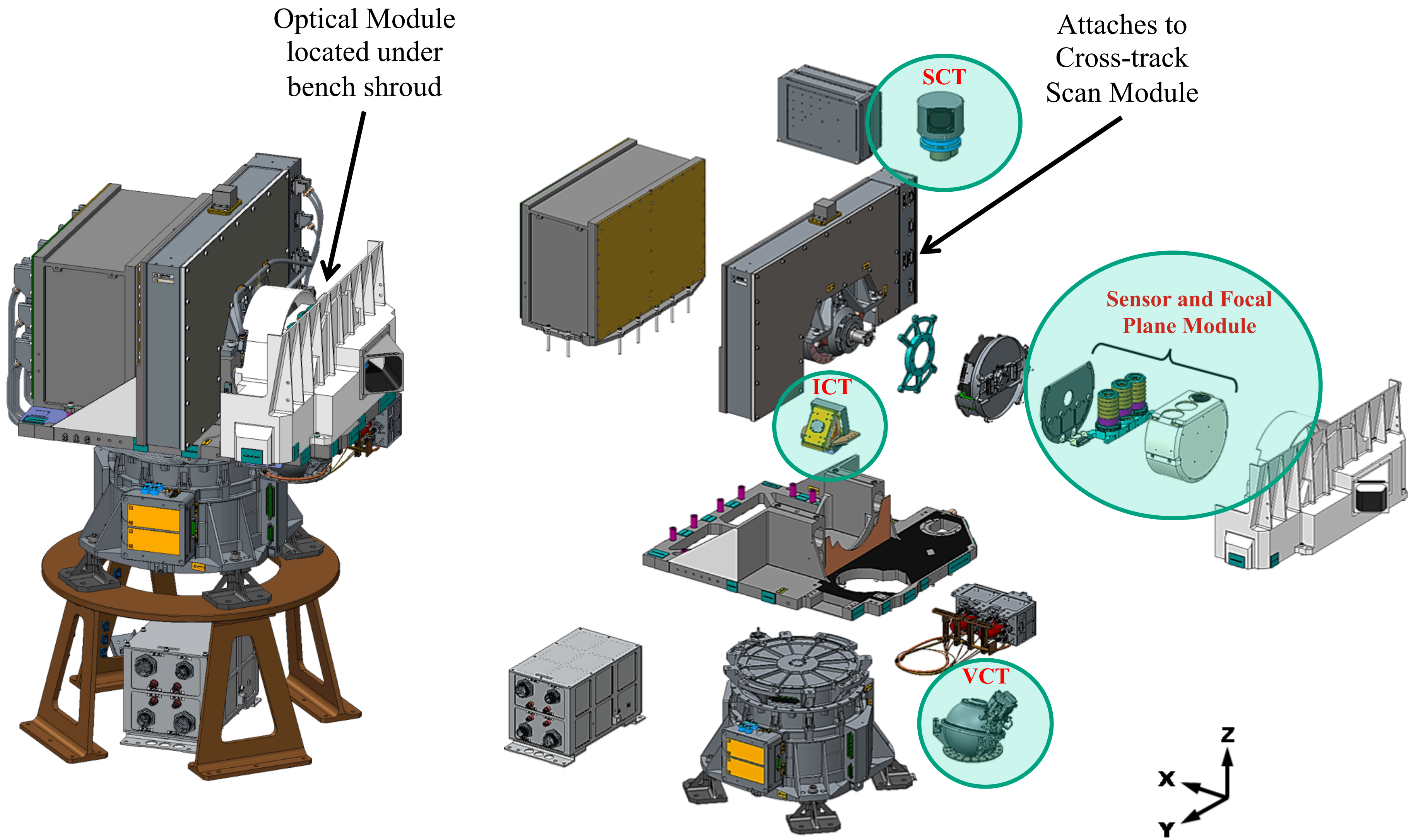
Model: 2 Elements



Model: 2 Elements



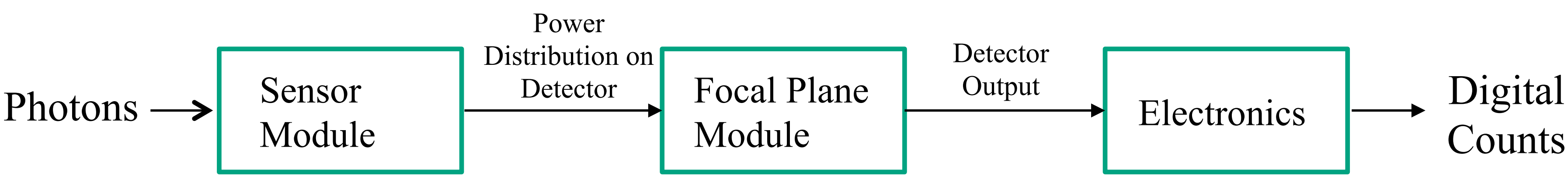
Radiation Budget Instrument



RBI Instrument Model Objectives

Develop a tool to enhance the interpretation of Instrument performance

- Model the end-to-end science signal chain: Photons in to bits/counts out.

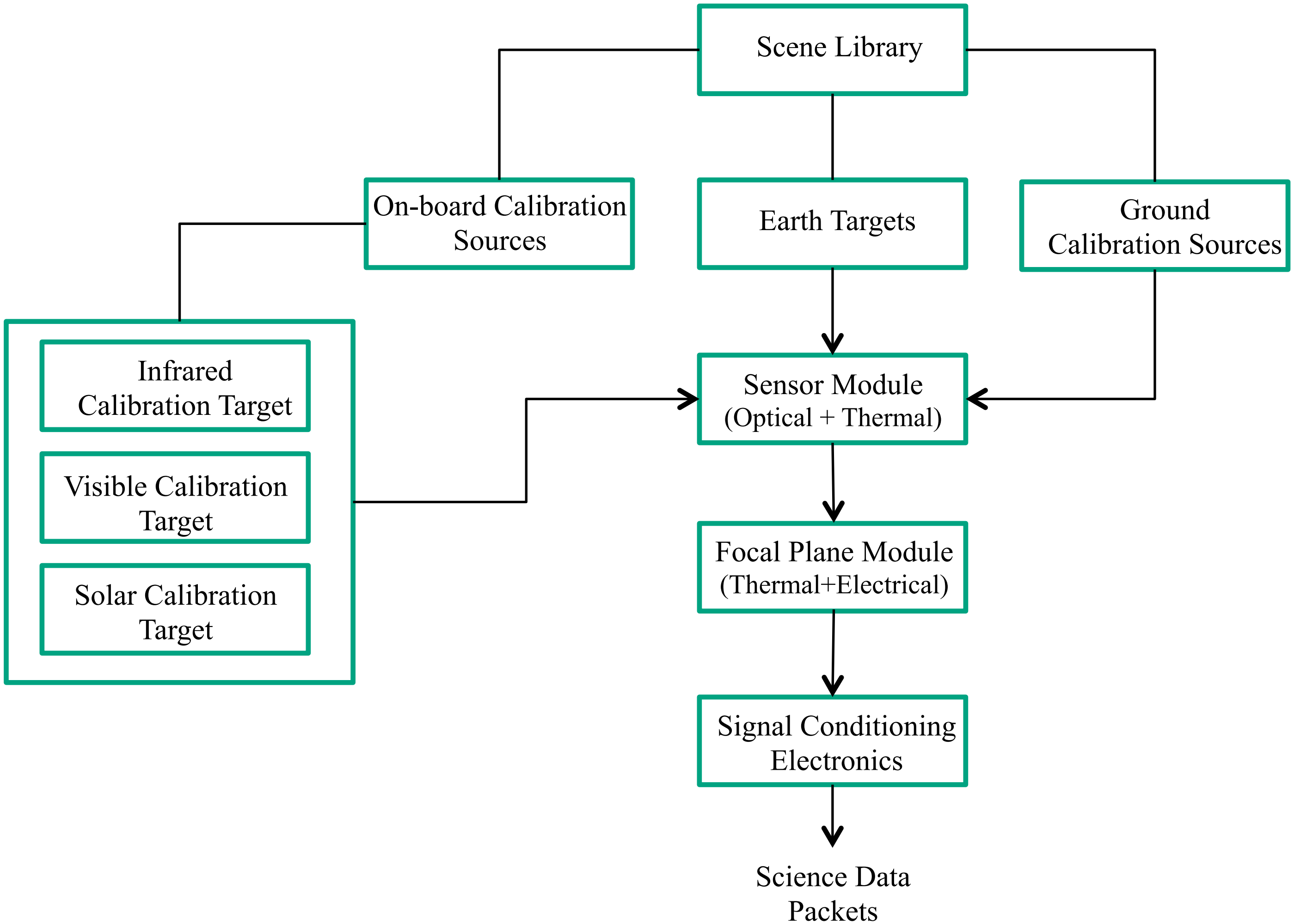


- Simulate the science data stream output when viewing calibration targets, earth scenes or any user-defined radiance.
- Support and validate engineering design and fabrication phase.
- Quantify the effects of various anomalous sources of energy arriving at the focal plane
- Quantify uncertainties in knowledge of the system parameters- ICT temp, paint absorptivities, BRDFs, dimensional tolerance, etc.

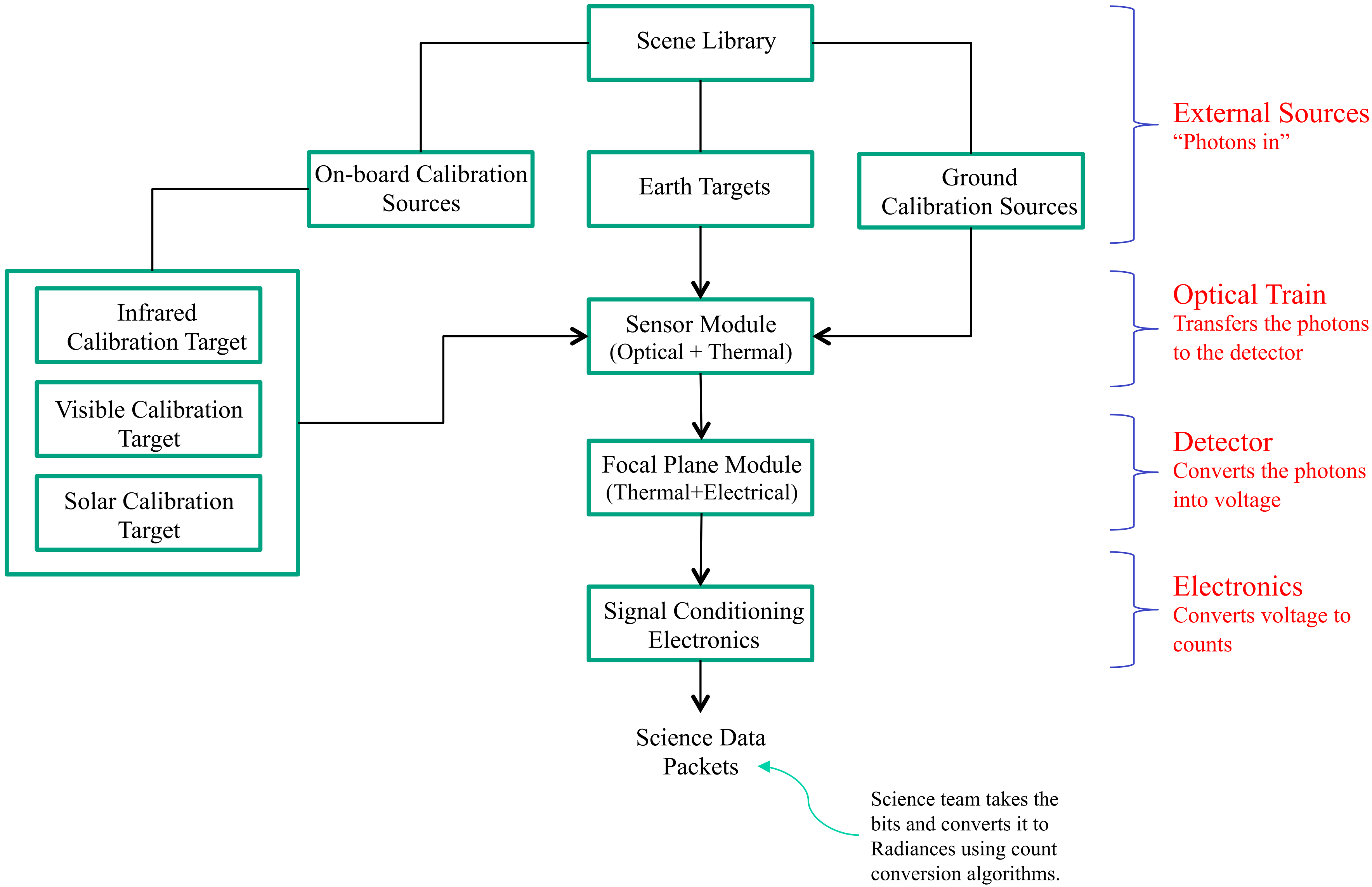
Numerical Modeling Tools

- Monte-Carlo Ray-Trace Tool
  - Computes the distribution of radiation within the instrument.
  - Spectral characterization of the optical and radiative performance of the entire instrument.
  - Provides the necessary "Boundary" conditions for the thermal models.
- Detector Electro – Thermal Model
  - Three-Dimensional characterization of the transient thermal diffusion in the detectors using a finite-difference approach
- Electrical Circuit Model
  - Computation of the electronic Response of signal conditioning electronics.
- Zemax Optical Design Software (Validation tool)
  - Uses ray-tracing principles to design and analyze imaging systems.
- Thermal Desktop (Validation tool)
  - CAD based approach that allows for temperature mapping using finite difference and finite element approach.
- Previous Earth Radiation Budget (ERB) programs, such as CERES, have used these modeling efforts for End-to-End characterization of the instrument

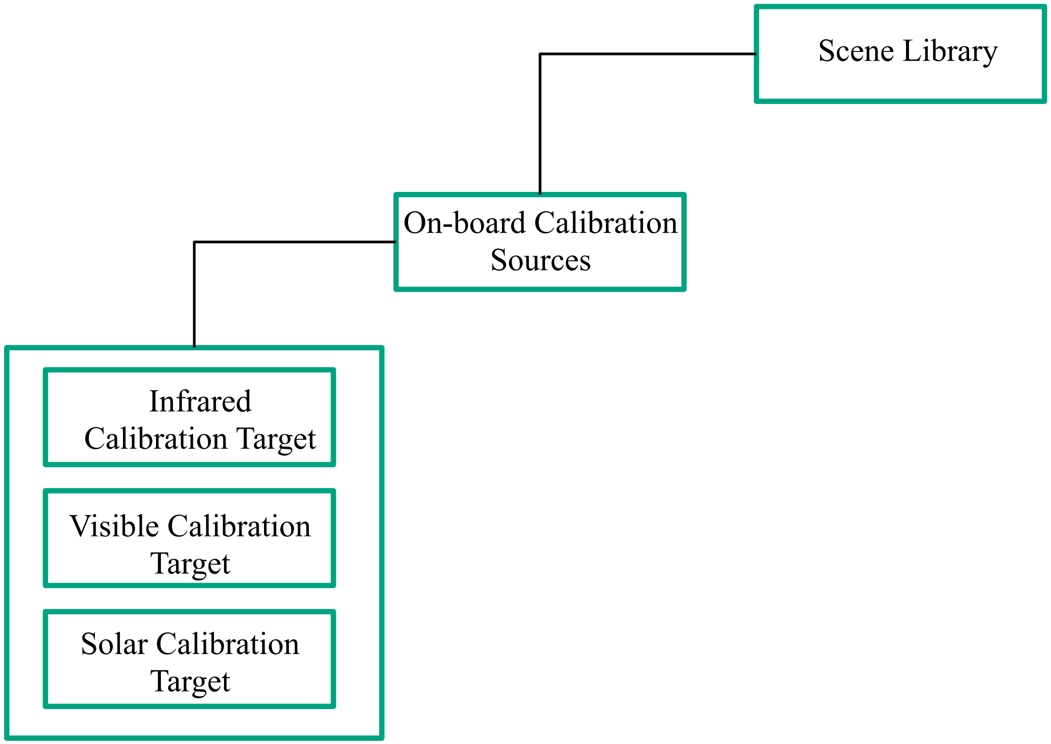
Modeling Framework



Modeling Framework



Modeling Framework

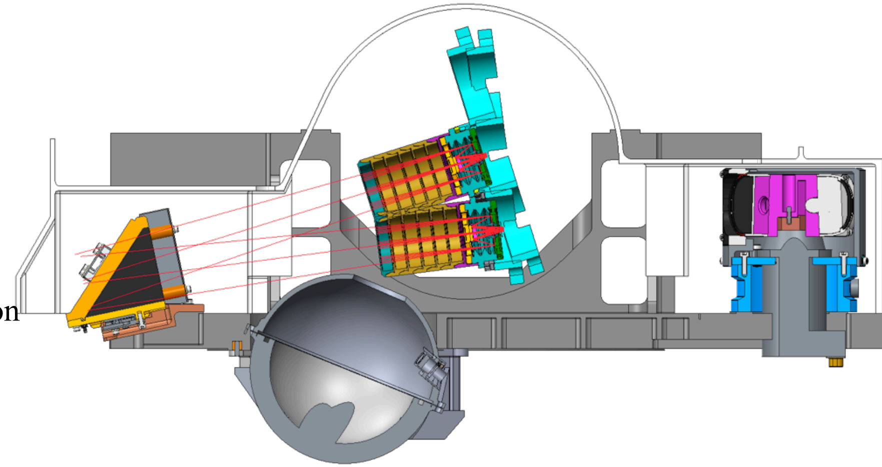


Modeling Framework

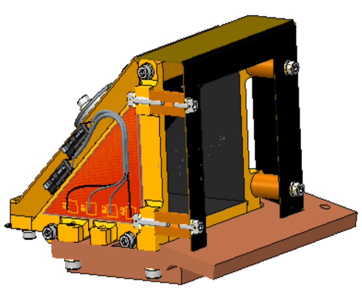
On-board Calibration Sources

- **Infrared Calibration Target**
- Visible Calibration Target
- Solar Calibration Target

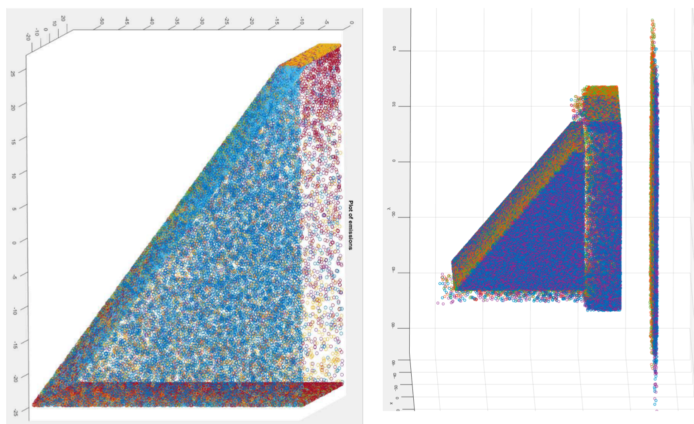
- **Infrared Calibration Target (ICT)**
- Positioned to be viewed by Total and Longwave Channels
- Spatial and spectral output distribution imaged on the Focal Plane
- Coated with Z-302 paint



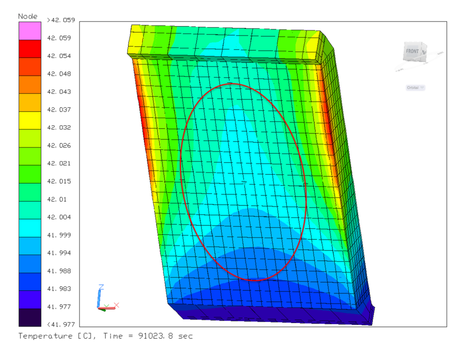
Infrared Calibration Target (VCT)



Creo model was used to provide geometry and surface properties



- Modeled in MATLAB using MCRT techniques.
- Computes the distribution of radiation within the ICT, taking into account direct radiation and all possible reflections.
- Power leaving the ICT exit aperture is captured and used to determine the spatial and spectral distribution on the IP



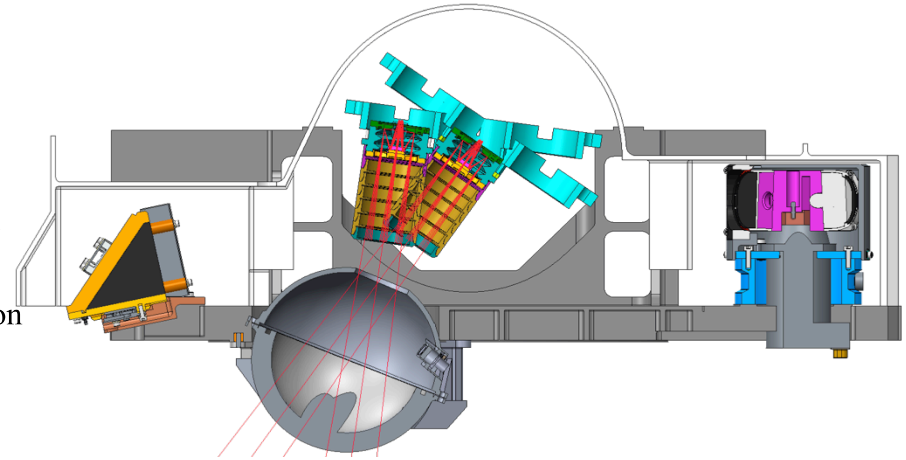
- Thermal analyses conducted in parallel to obtain temperature profiles
- Thermal gradients within the ICT can produce ambiguous radiance

Modeling Framework

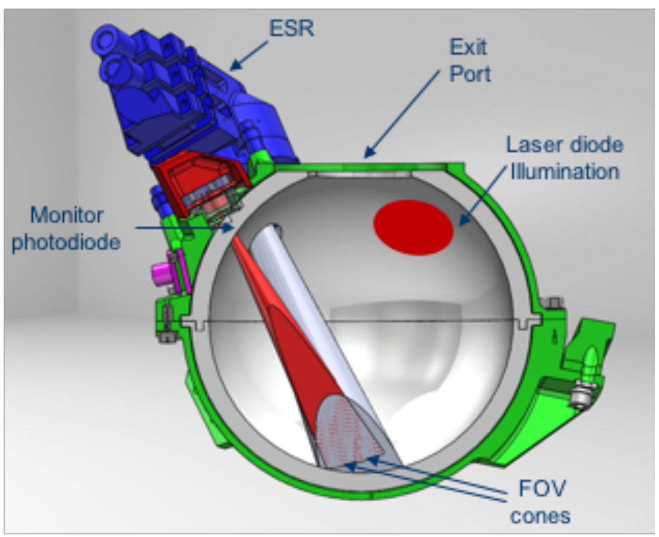
On-board Calibration Sources

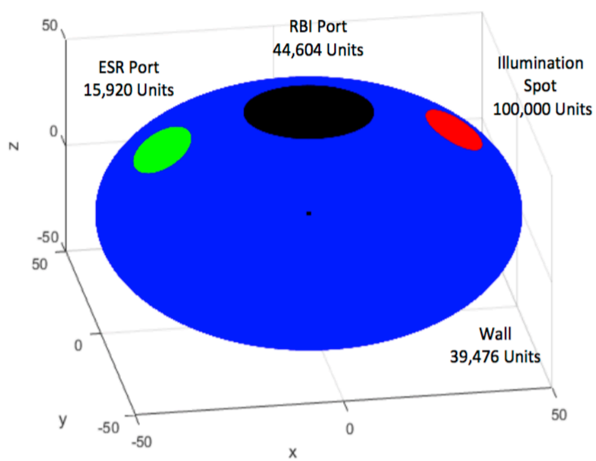
- Infrared Calibration Target
- Visible Calibration Target
- Solar Calibration Target

- **Visible Calibration Target (VCT)**
- Positioned to be viewed by Total and Shortwave Channels
- Spatial and spectral output distribution imaged on the Focal Plane
- Space grade Spectralon covering the inner sphere



Visible Calibration Target (VCT)





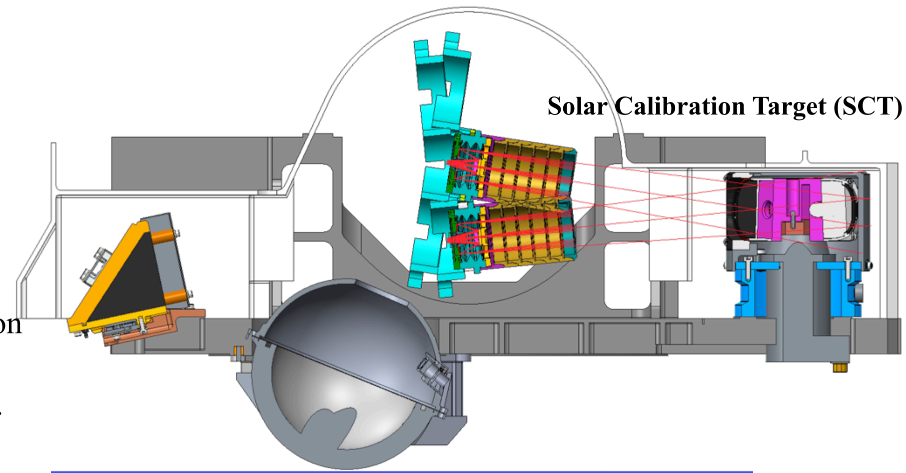
- Modeled in MATLAB using MCRT techniques.
- Computes the distribution of radiation within the VCT, taking into account direct radiation and all possible reflections from the Spectralon coating.
- Power leaving the VCT exit aperture is captured and used to determine the spatial and spectral distribution on the IP

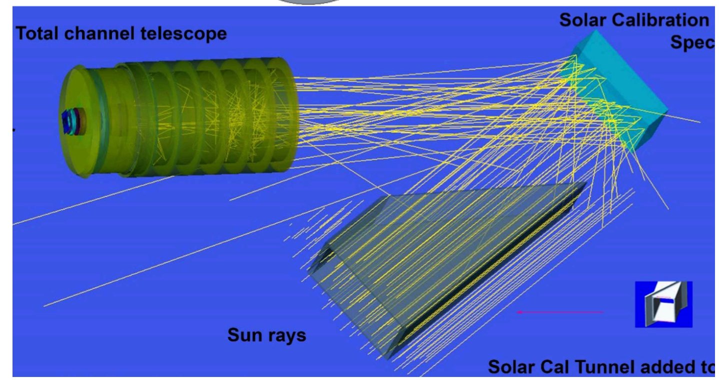
Modeling Framework

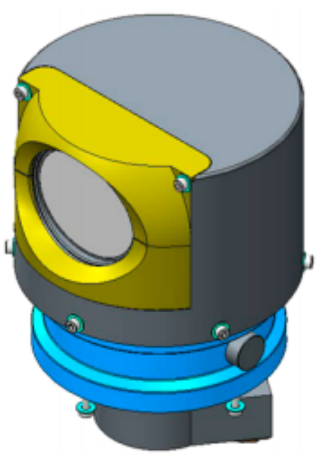
On-board Calibration Sources

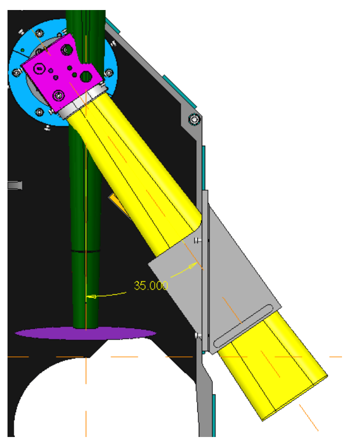
- Infrared Calibration Target
- Visible Calibration Target
- Solar Calibration Target

- **Solar Calibration Target (SCT)**
- Positioned to be viewed by Total and Shortwave Channels
- Spatial and spectral output distribution imaged on the Focal Plane
- Contains 3 protected spectralon solar diffusers to provide cross check with VCT and used to provide indirect solar cal.





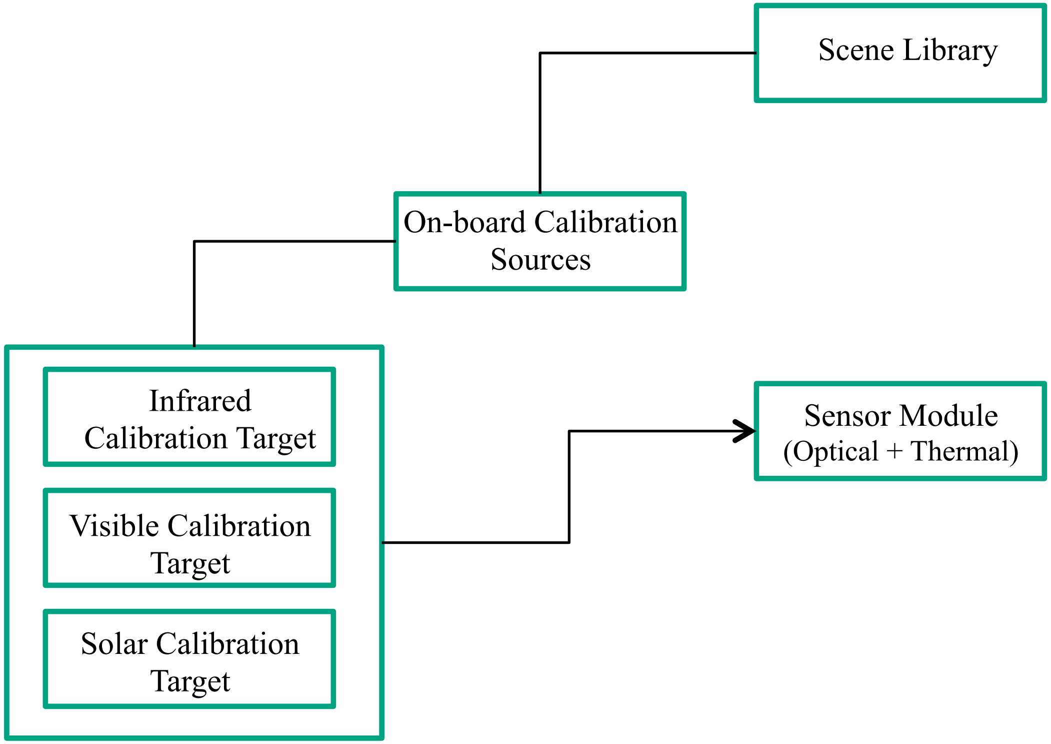




Visual does not reflect the current geometry,
But the model itself does

- Modeled using MATLAB (primary) and Zemax Optics Studio (verification)
- Parameters such as optical prescription, viewing geometry, and paint specs are also being modeled.
- Computes the distribution of energy that would arrive at the exit port of the SCT during a solar cal, taking into account direct radiation and all possible reflections.
- Power leaving the SCT exit aperture is captured and used to determine the spatial and spectral distribution on the IP

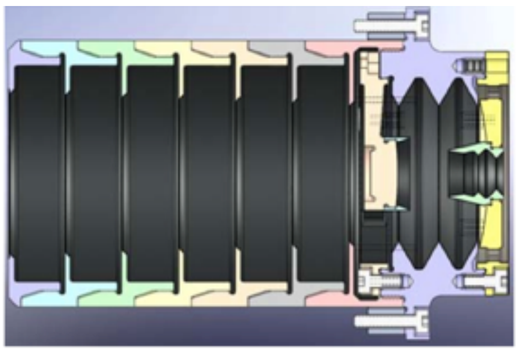
Modeling Framework

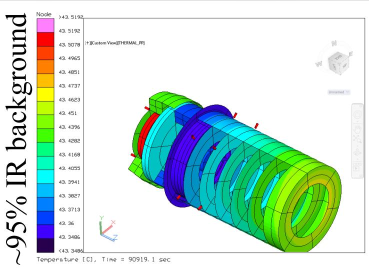


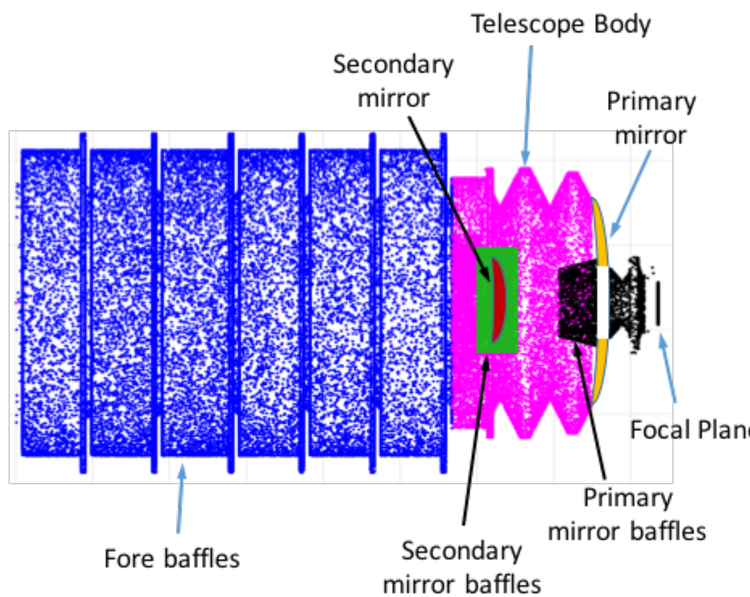
Modeling Framework

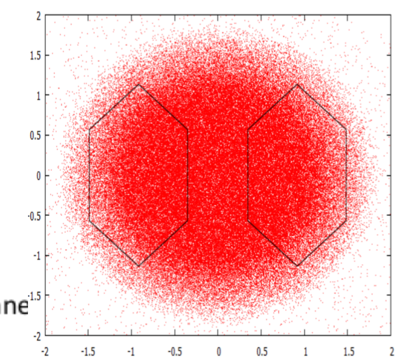
Sensor Module
(Optical + Thermal)

Fore Baffle → Telescope (includes primary and secondary baffles) → Spectral Filter (SW and LW) → Image Plane



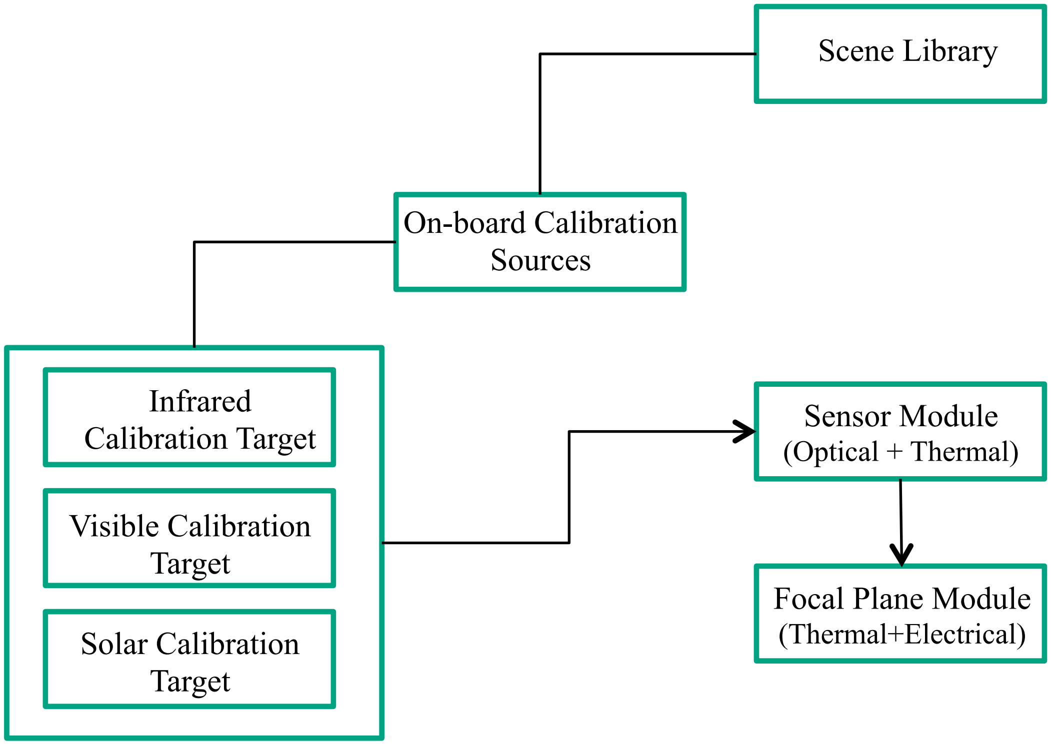






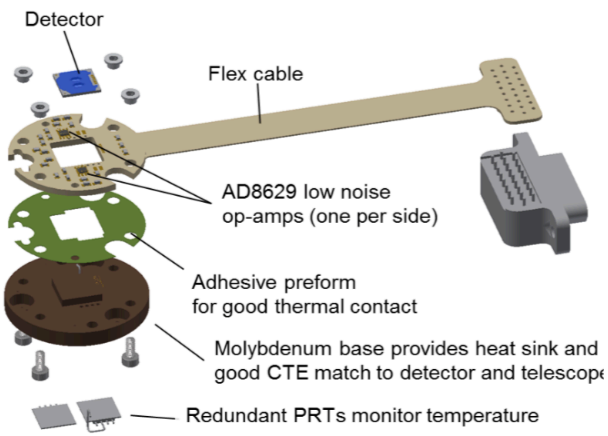
- Being developed using MCRT techniques to model the geometry and compute the distribution of radiation within the telescope and how it arrives on the image plane (focal plane). Produces a time-series of radiation arriving at IP.
- Has helped identify possible sources of stray light and has been used to study effects of certain design changes.
- Transient Thermal analysis is being conducted in parallel to assess background IR signal

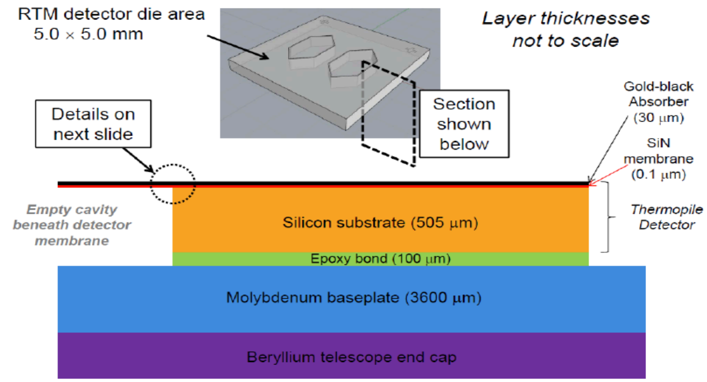
Modeling Framework

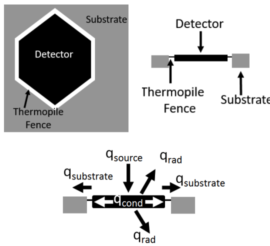


Modeling Framework

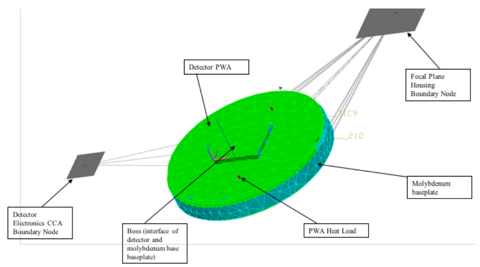
Detector
(Thermal+Electrical)

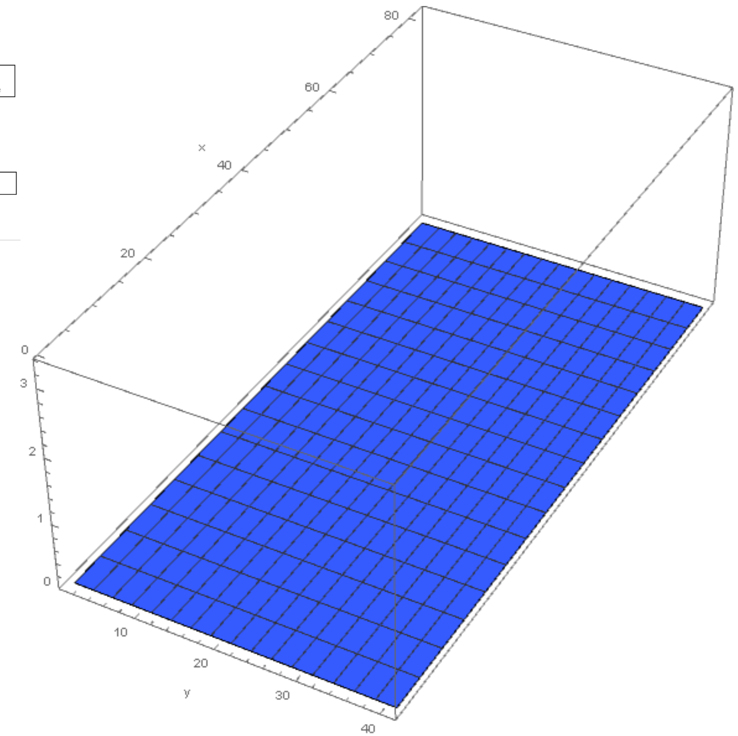






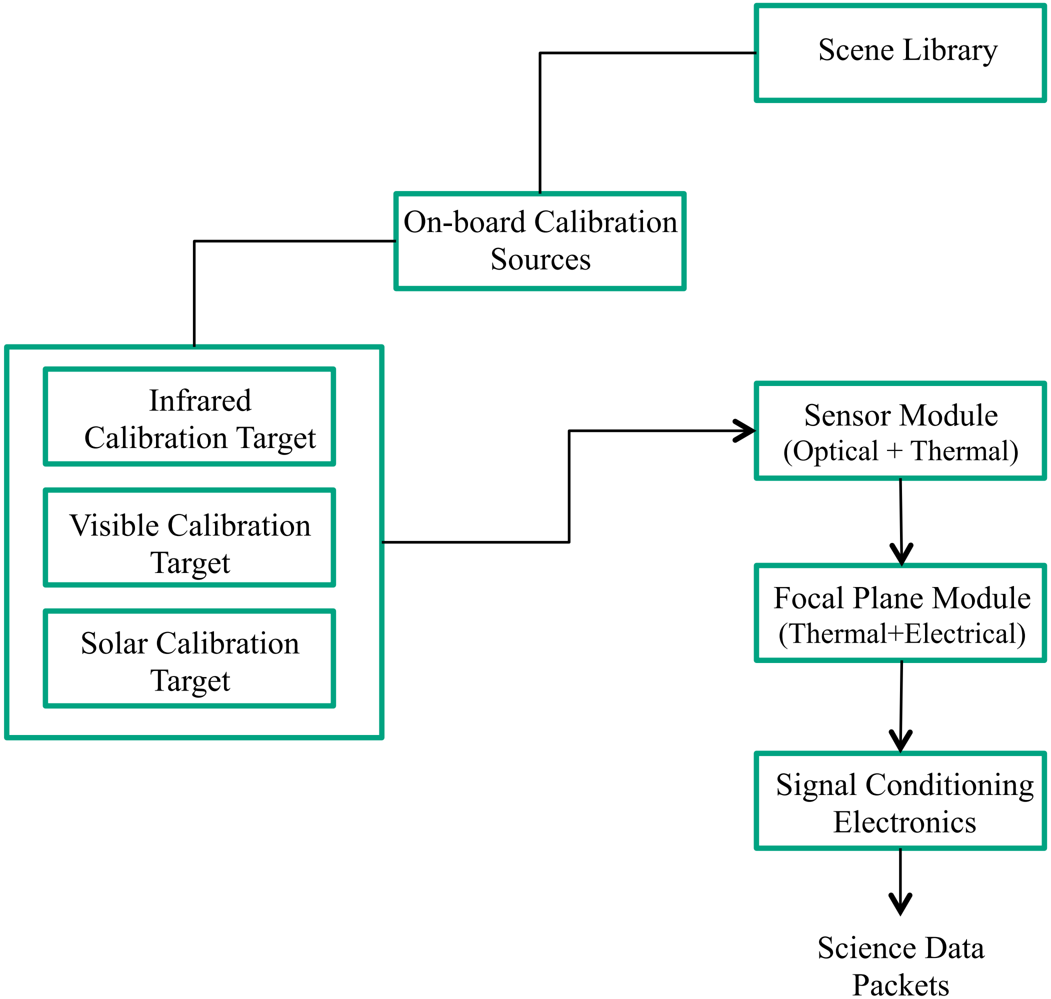
Note: Illustration shows only 1 of 2 detectors on focal plane





- This module consists of the two thermopile detectors housed on the Molybdenum baseplate.
- Electro-Thermal diffusion model uses a finite difference technique with given knowledge of detector properties to convert a time-varying power distribution on the detector to a voltage time series signal.
    - Voltage is induced due to the temperature difference across the thermopile fences.
- The analysis from the thermal model provides us with the BC for the Electro-Thermal model
- Provides a time-series of voltages to be processed through electronics signal chain

Modeling Framework



Modeling Framework

Signal Conditioning Electronics

FPM = Thermopile detector + preamp

DE Board = PGA + ΔΣ modulator

FPGA
Includes Bessel filter

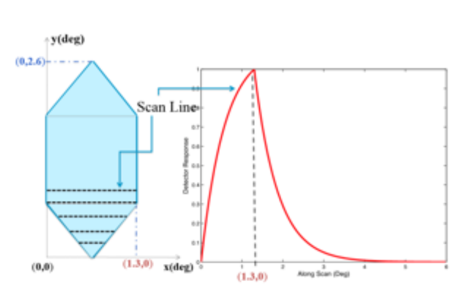
Data received from the thermal diffusion model is processed on the focal plane module.

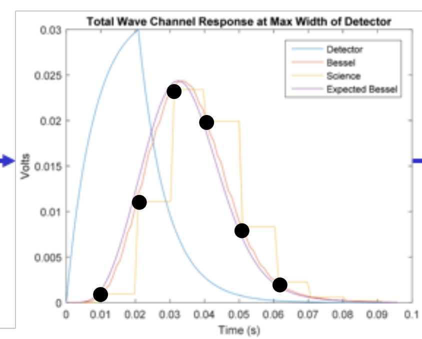
The amplified analog signal is then processed on the detector electronics board and converted to a digital signal using the A/D converter.

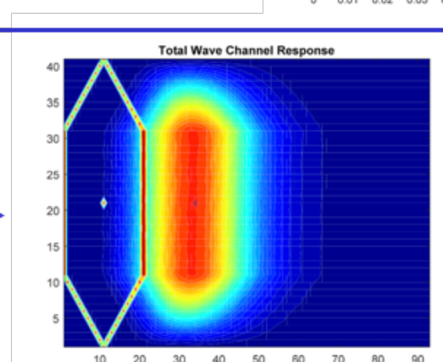
The digital signal is then processed through a Bessel filter to provide the science output.

Model accepts the signal voltage (time series) and provides 20-bit science data at 100 samples per second.

1st order PSF studies

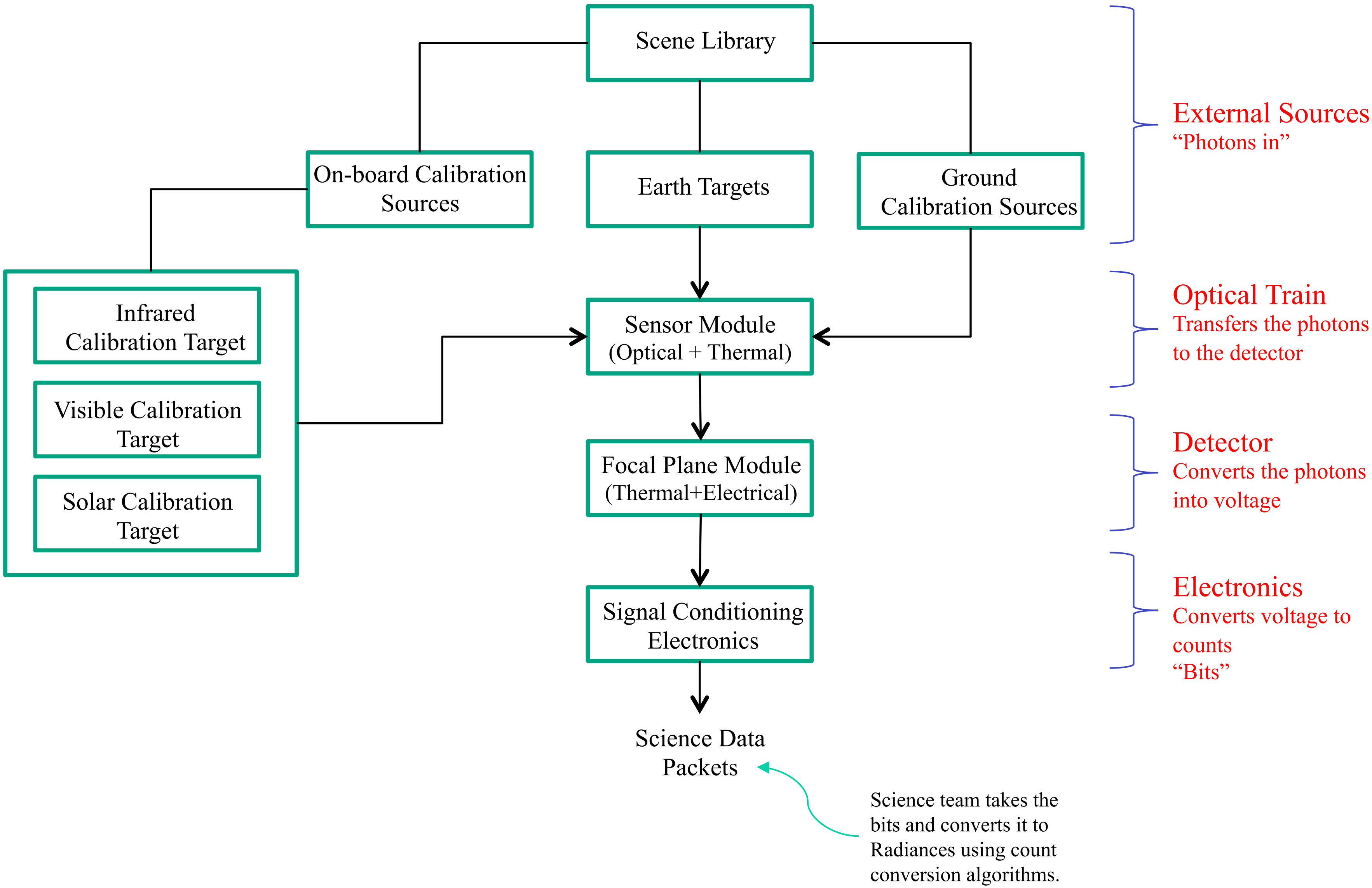




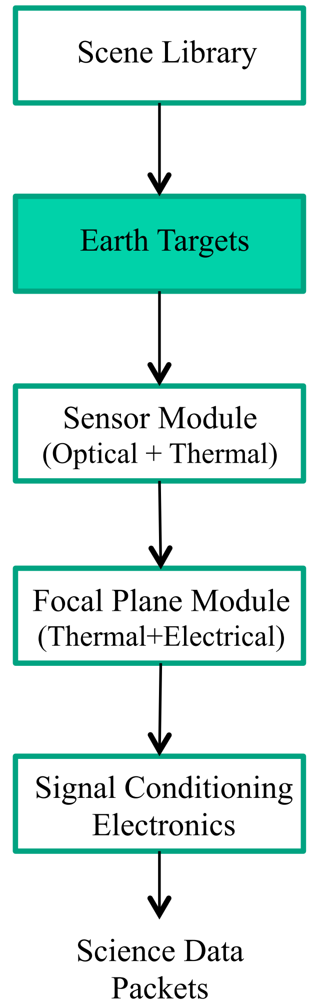


PSF Simulation

Modeling Framework



Modeling Framework



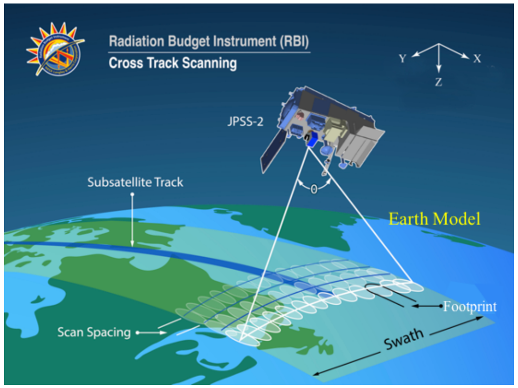
Earth Model Objectives

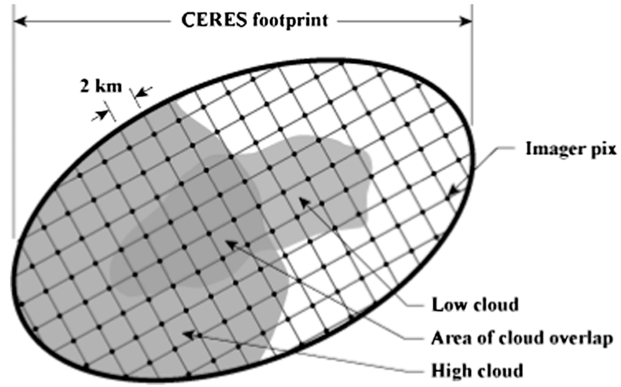
Develop a tool to evaluate impacts to science data products due to tolerances in instrument design

- Implementation:
  - Use CERES datasets to develop a realistic Earth model, including spatial, spectral, and temporal variations in scene type: geo type and atmospheric state.
- Utilization:
  - Evaluate proposed con-ops by scanning this earth model with the instrument model.
  - Evaluate sensitivities in the data products that result from:
    - various anomalous sources of energy arriving at the focal plane
    - uncertainties in knowledge of the system parameters- ICT temp, paint absorptivities, BRDFs, dimensional tolerance, etc.

Building Synthetic Earth Model

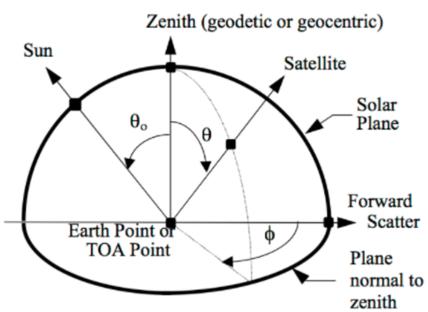
Model will be comprised of synthetic orbits with properties defined on a ~2km grid



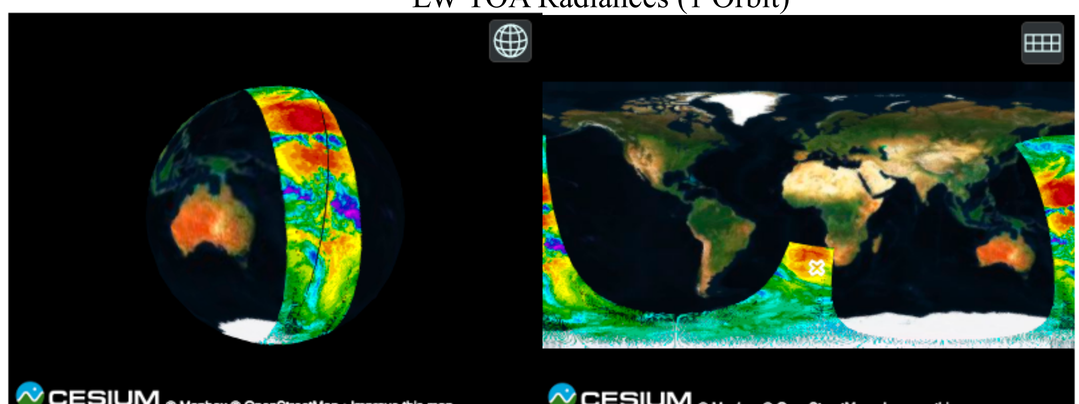


Will require multiple auxiliary datasets and various algorithms working together.
We will use modified CERES algorithms and high resolution imager data from MODIS/VIIRS to define ~2km grid in terms of:

- Geo type and atmospheric state
- Viewing geometry
- Sun illumination geometry

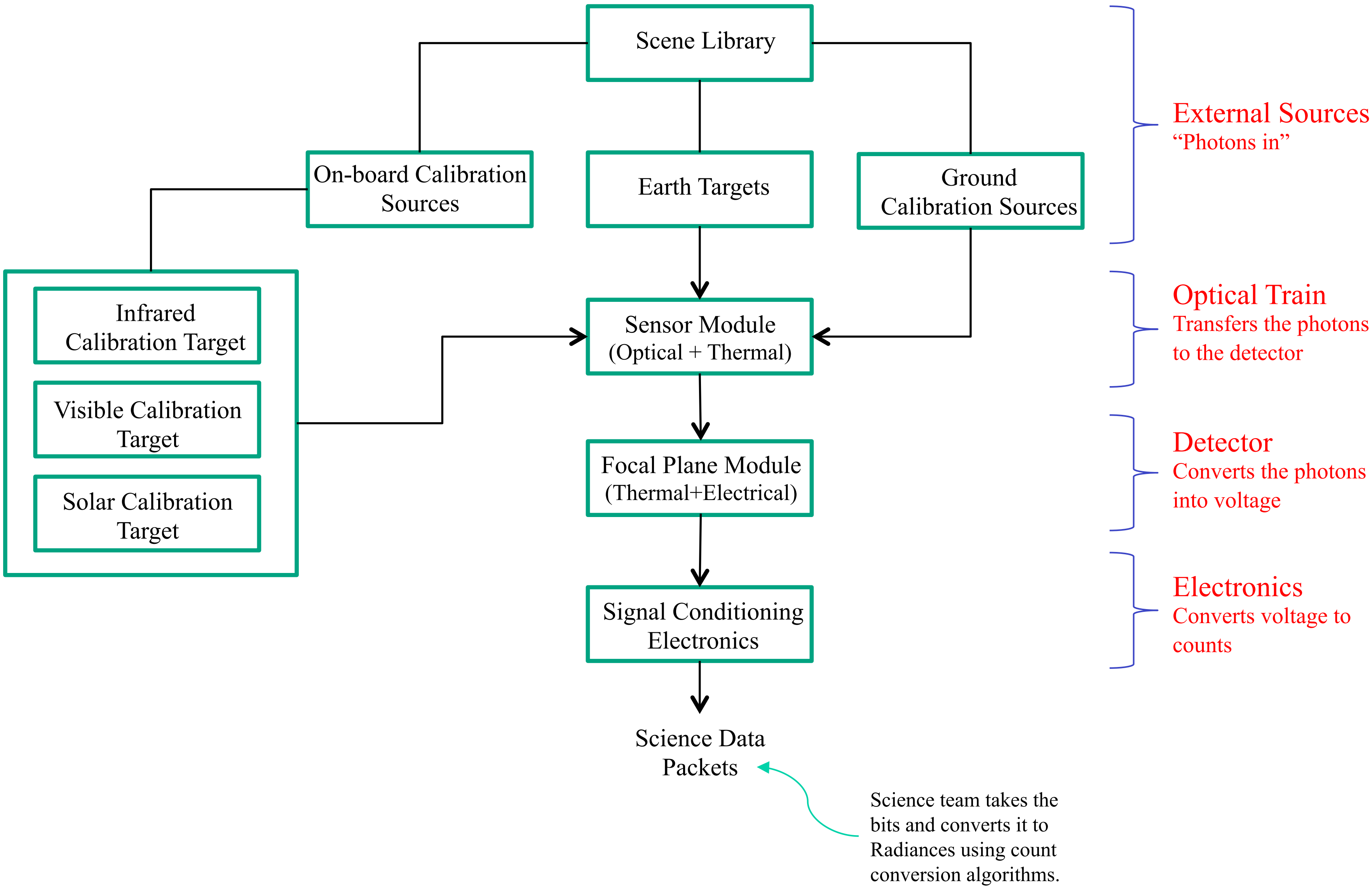


LW TOA Radiances (1 Orbit)



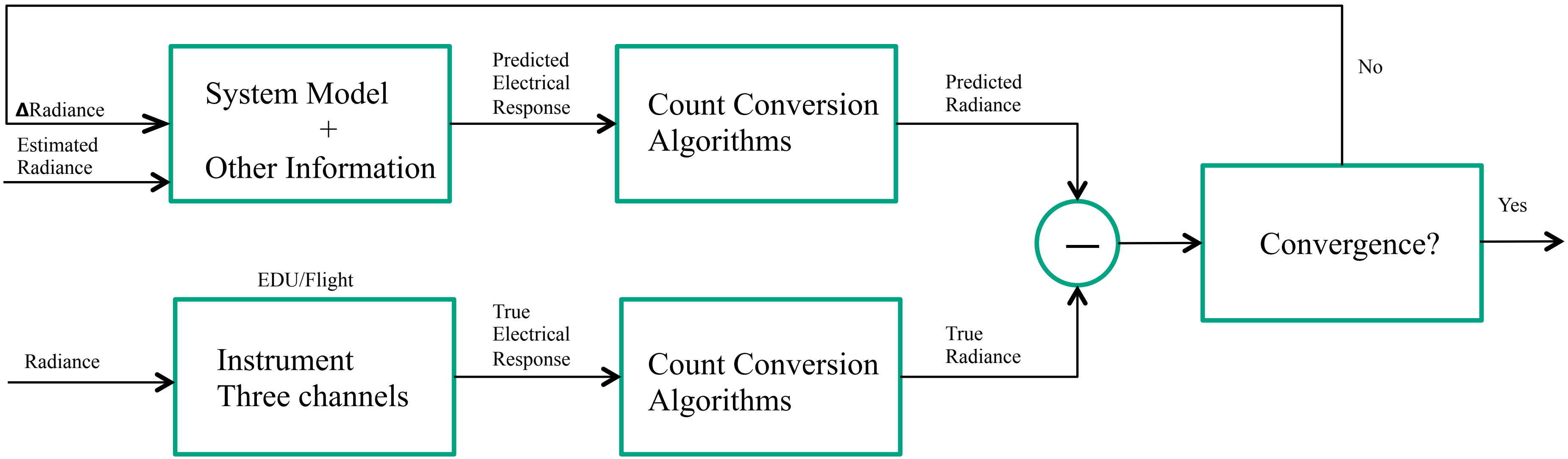
This will provide us with a complete description of a radiation field the instrument will capture if it was scanning in that orbit.

Modeling Framework



Correlation of Model to Hardware

- During System Level TVAC testing we will simulate the test execution with the model to complete an end-to-end correlation.
  - On-board and ground calibration sources
- If the system model and hardware do not converge, we will perturb model parameters within their allowed tolerances to bring the model and hardware into agreement.



Current Status

- Currently in Build 2 phase: All subassemblies have been developed in MATLAB.
  - ✓ Design changes for EDU build were incorporated as engineering drawings become available
- Methodology for developing geo scenes has been defined and is currently being developed
- Interface between source (calibration or earth) and telescope are being developed.
- On-going thermal analysis supports and validates contractor's derived requirements for individual subsystems (ICT, telescope)
- Short-term studies that can influence instrument design were also carried out in parallel
  - ✓ Stray light studies
  - ✓ SW filter heating and re-emission
  - ✓ Temperature variations in telescope baffles due to material change
  - ✓ PSF studies
- On-going sensitivity analyses are underway - uncertainties in radiance arriving at telescope aperture due to:
  - View angles for all three telescopes to the sources.
  - Uncertainties in knowledge of the system parameters- ICT temp, paint absorptivities, BRDFs, etc.
- Future investigations include investigating differences in instrument response to on-board and ground calibration sources (Traceability of calibration).

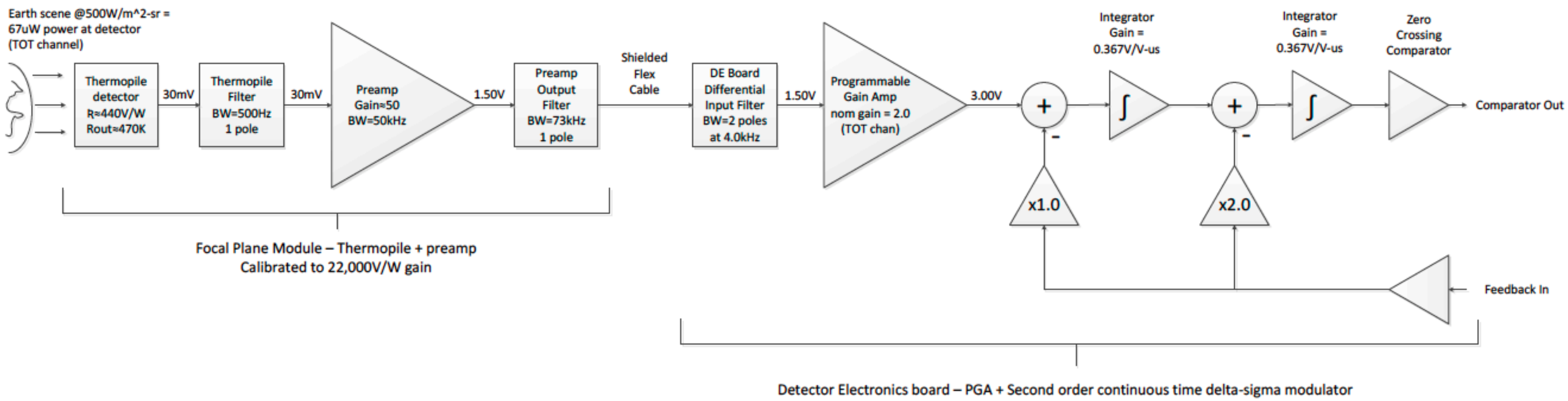
Questions?

Electronics Signal Chain

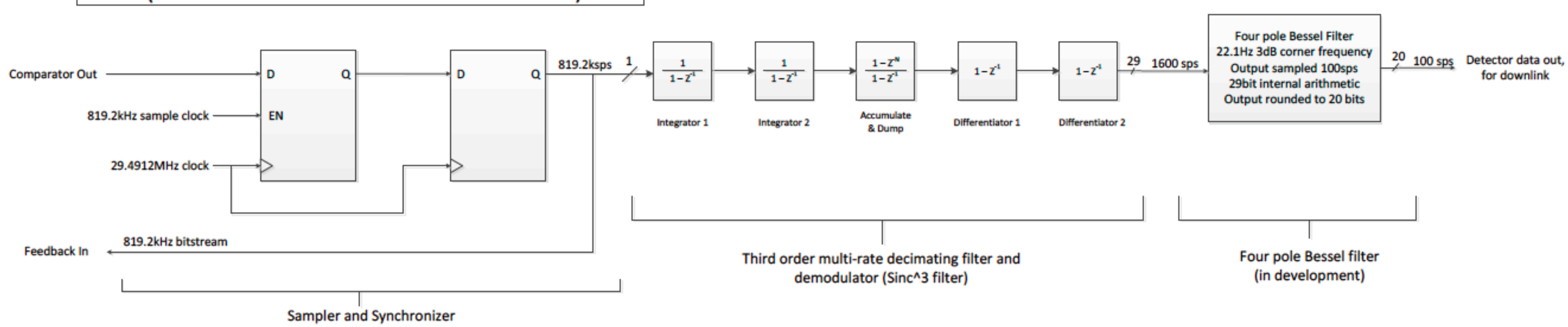
RBI-15-376 rev A - RBI Science Data Processing Chain

Figure A1 – TOT channel

RBI science data analog processing chain



RBI science data digital processing chain (inside Detector Electronics FPGA)



Future Work

- Parametric analysis within the instrument to help us assess impacts to radiometric performance due to degradation of surface properties
  - Z302, Z306, micro-balloons, Spectralon
- Inter-comparison of the three channels: dynamic co-location and how that influences the data products
  - Mismatch of time constant that influences the PSF assumed for the three channels
- Investigate differences in instrument response to on-board and ground calibration sources (Traceability of calibration).
- Propose techniques to assist in interpretation of earth observations.